Laboratory Studies of Density Increase on Shelves

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LONG TERM GOALS

The long-term goal is to understand the fluid mechanics of buoyancy and wind driven transport on a polar continental shelf, including along-shelf transport and exchange with the deep Arctic Ocean.

OBJECTIVES

To understand flows in scaled laboratory experiments in a manner suitable for application to processes in physical oceanography.

APPROACH

Prototype laboratory experiments are designed and approximate theories and scaling are laid out. Their results indicate design requirements for refined experiments that yield observations of flow patterns and quantitative measurements of important parameters. These are compared with theory and ocean data.

ACCOMPLISHMENTS

We are conducting four laboratory studies of fluid mechanics processes with applications to Pan Arctic shelf/basin environments (1) Laboratory experiments reveal the features of a dense plume of salt water flowing down a slope in a rotating fluid with lower salinity. Over a wide range of parameters three flow types are found: laminar flow, waves, and eddies. Regime diagrams illustrate the range of variables that produce these three different types, and the parameters indicate some aspects of the dynamics for their formation. (2). A simplified box model of the cooling of a salt-stratified ocean is analyzed analytically, numerically, and in the laboratory. We find that cooling a body of salt water that has a layer of fresh water at the surface can result in two states of motion for the same surface cooling conditions. In one state, the fresh surface water is cooled and the convective circulation is shallow. In the second, salt water is entrained and deeper convection of mixed water occurs. This model may apply to convection by ice formation in Polynias. It also may apply to plumes of freshened river water in early winter. The results show that the formation rate of dense salty water may be quite limited for small cooling rates, but one strong cooling event can trigger intense formation rates that may persist vigorously for the rest of the winter. (3) Hydraulic jumps are found when a fast supercritical current slows to a specific speed and "jumps" to a slower state, accompanied by intense mixing and turbulence. We have been investigating the behavior of jumps upstream of an obstacle and find that the presence of the jump, and hence the mixing made by the jump, depends on the history of the way the flow was started.

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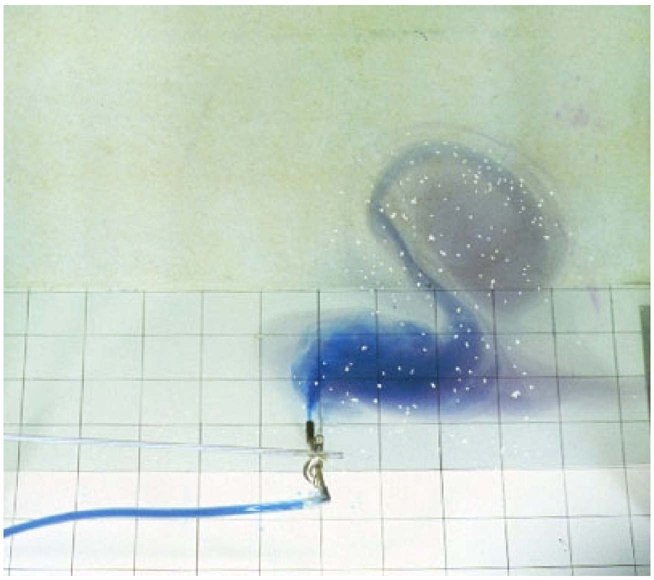
(4) The possibility of vortex generation is investigated as a current of dense water descends down a gentle slope and then encounters steep shelf break topography. Laboratory experiments on a rotating turntable (to simulate earth rotation) possessed the geometry present near the north-eastern part of the Chukchi shelf: a canyon with a gentle slope (Barrow Canyon, Alaska) and a steep continental shelf break in contact with deep water (Arctic Ocean). This simplified model produced eddy formation when the dense fluid moves from a gentle slope in a shallow environment, such as the Chukchi shelf, to a steep deep environment , such as the shelf break.



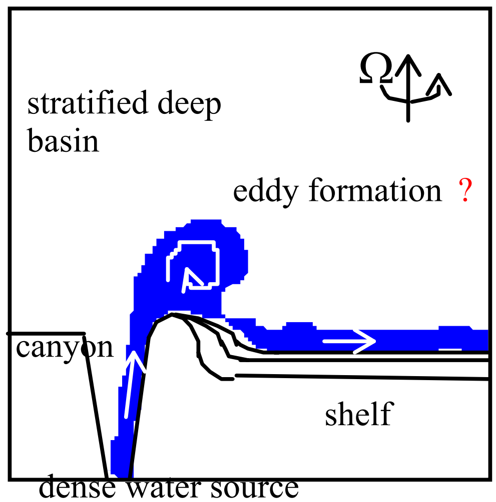


Figure 1. (Left) View from above of a laboratory eddy formed from a jet source of blue dense salty water over sloping topography in linearly stratified rotating water. The eddy is detaching from the bottom and moving into the interior of the basin. (Right) Sketch of recent refined experiments. Flow down a canyon replaced the point source. For some parameters, the eddy detached and propagated into the interior of the deep basin.

RESULTS

(1) Dense water descended a uniformly sloping bottom from a point source. Over a wide range of parameters the experiments show three flow patterns, laminar flow, roll waves and eddies Kelvin-Helmholtz instability seems the most likely candidate for roll-wave generation which may be associated with more intense mixing between shelf and Arctic waters. The eddy instability may be associated with eddy formation in the Arctic Ocean. All three types may be expected in the shelf break at the edge of the Barents and Chukchi Seas. (2) Theory and experiments show that the strength of dense water formation is likely to display hysteresis and sensitivity to small factors such as a thin layer of fresher water and frictional drag. (3) Hysteresis of hydraulic jumps is going to make prediction of flows and mixing extremely difficult for some conditions. Although we have measured such features in the laboratory, finding and documenting such effects in the ocean may be very challenging. (4) A gravity current descends a canyon and encounters a steep shelf break. We find that eddies can form and detach from the shelf break.

IMPACT/APPLICATIONS

The dependence of dense water formation strength and hydraulic jump location on history will introduce strong challenges to numerical modeling and ocean observations. For example oceanographers might come to a site and find intense turbulence, yet upon reoccupying this site, find no such turbulence later, even though the same currents and stratification characterize the region. Some quantitative criteria have been found to help oceanographers determine where convection is likely to be found. Parameters that determine the emergence of mixing and the detachment of eddies into the Arctic ocean are becoming more clearly known. Ekman layer processes, Kelvin-Helmholtz waves, and hydraulic jump processes made their own distinct contribution in shaping the form of the current and in some cases breaking it up into eddies.

TRANSITIONS

In all problems we intend to describe these and related processes clearly in a manner accessible to oceanographers and students. The results suggest a number of measurements in the Chucki sea that are desirable.

RELATED PROJECTS

Fundamental research into multi-equilibrium flows in laboratory devices driven by multiple forcing sources, and application in physical oceanography and climate is supported by NSF Grant OCE-00-81179. Hydraulic jump research work is conducted in collaboration with Dr. Peter Baines of the CSIRO Atmospheric Research, Aspendale , Australia. This work also builds upon results of Chapman and Gawarkiewicz (1995), Chapman and Gawarkiewicz (1997), Gawarkiewicz and Chapman (1997) and Chapman (1998) that set many of the dynamic constraints of the ocean response to isolated convection on shelves.

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